GEOLOGY.—*A revision of the Pleistocene Period in North America, based especially on glacial geology and vertebrate paleontology.* OLIVER P. HAY, Carnegie Institution of Washington.

1. EXPLANATORY

For some years the writer has been studying the fossil vertebrated animals of the North American Pleistocene period in the endeavor to determine the genera and species which then existed, the geological stages during which the various species lived, their origin, their distribution, and the causes of the disappearance of as many as did disappear. Naturally, it has been necessary to study the geology of the Pleistocene, in order to correlate the history of the animals with the geology.

For the writer the Pleistocene is synonymous with the Glacial period. As regards the beginning of this period, we may not know when the first accumulations of ice began at the centers of radiation in Canada; but we may credit to the Glacial period such phenomena in southern British America and in the United States as (1) glacial drift produced from a continuous sheet of ice; (2) moraines from local glaciers provoked by a general lowering of the climate; (3) the disturbance of the previous drainage. The close of the Pleistocene was marked by the retreat of the last ice sheet to its center in Labrador.

I accept the results of the glacialists who seem to have established the occurrence of five glacial and four interglacial stages. During these stages there appear to have been produced such important effects, geological and biological, that they mark off as many distinct divisions of the Pleistocene period; but not all of them have the same value.

2. THE VICISSITUDES OF THE PLEISTOCENE VERTEBRATES

In considering the vertebrate palaeontology of North America during the Pleistocene, the following facts need attention. Had it not been for certain geological changes which occurred just before or at the beginning of the Pleistocene, our continent would have been occupied by animals very different from those found here when Columbus made his discovery. The occupants would have been purely the descendants of the late Tertiary animals. There would have been found strange carnivores, probably various saber-tooth tigers; one-toed, probably also three-toed horses; tapirs; various species of camels

and peccaries; short-jawed and long-jawed mastodons; possibly rhinoceroses. However, movements of the earth's crust opened the gates of Asia and of South America and permitted hosts of vertebrates to enter from those lands. From South America there arrived six or more genera of giant ground-sloths, large and small armadillos, glyptodons, and huge capybaras. A few of these had filtered in during the upper Pliocene, but most of them apparently during the wane of the first glacial stage or early in the first interglacial.

From Asia there came, in at about the same time, elephants of several species, the American mastodon, probably most of the Pleistocene and Recent dogs and cats, the bears, and the bisons, musk-oxen, sheep, and reindeer; also moose of two or three genera. Hence, shortly after the beginning of the Pleistocene, at least early in the first interglacial stage, there was an abundant and varied fauna, the product of three continents. There were copious materials from which new forms might be evolved, and the environment seemed favorable. What was the result? When white men reached this country the fauna had become impoverished. Orders, families, and genera, especially of large mammals, which were present at an early stage of the Pleistocene, had disappeared. All the great edentates, the ground-sloths, the glyptodons, and the great armadillo *Nothrotherium*, also the capybaras, sent north from South America, had perished. The saber-tooth tigers had become extinct; the whole order of elephants and mastodons had been swept away. Of more than a dozen species of horses which had existed, none was left. Of six or more kinds of bisons, only one remained.

Had other forms been evolved to take the places of those species which had been exterminated? Assuredly, during that time no new family had been evolved. Probably not even a new genus had come into existence. It may be that certain forms had developed some of the small differences that mark species. It was, however, a time of extinction of species, and a time of little evolution. How can we account for this zoological catastrophe? The interglacial stages were certainly favorable for plant and animal life. Apparently it was the glacial stages which brought about the extinction of so many imposing animal forms. The reasons are clear. The area for occupation was greatly diminished by the ice sheets. Much of the remaining area was made inhospitable to most animals and to their habitual food-plants. Snow storms and cold rains must have prevailed far southward and been conducive to the extinction of the less hardy species.

3. THE STAGES OF THE PLEISTOCENE

The stages of the Pleistocene are shown below. We know little from actual discovery about the vertebrate life of the first glacial stage, the Nebraskan; but it must have been made up of some species from South America, some from Asia, but principally of native species remaining over from the Pliocene. Many of the latter must have succumbed to the inclemencies of the climate. When the warm interglacial Aftonian came on, there were present, from persistence or from recent immigration, saber-tooth tigers, elephants (among them *Elephas imperator*), mastodons of several species, a dozen or more species of horses, several species of bisons, tapirs, camels, numerous ground-sloths, forming thus a rich fauna. Next came the Kansas glacial stage. After that stage we find few saber-tooths, no *Elephas imperator*, few species of horses, no camels, few species of ground-sloths, no glyptodons, no capybaras. The first glacial stage had thus almost annihilated the descendants of the Pliocene mammals, not inured to a severe climate. The second glacial stage had nearly wiped out the South American contingent. The survivors were mostly of northern Asiatic origin, hardened to an inclement environment. *Elephas imperator* had probably reached North America from southern Asia and was a weakling. The faunal change that occurred during the first three stages appears to have been more profound than that of the rest of the Pleistocene. Hence I believe that the division of the Pleistocene into Earlier and Later expresses best the history of the North American vetebrrate animals during the Pleistocene.

Pleistocene	Later	Wisconsin glacial. *Peorian interglacial.* Iowan glacial. *Sangamon interglacial.* Illinoian glacial. *Yarmouth interglacial.*	Few edentates, few or no horses, no camels, no *Elephas imperator*, one or two mastodons, fewer large cats.
	Earlier	Kansan glacial. *Aftonian interglacial.* Nebraskan glacial.	Many edentates, many horses, many camels, *Elephas imperator*, several mastodons, many large cats.

4. PLEISTOCENE GEOLOGY. THE EASTERN AND SOUTHERN COASTAL TERRACES

As regards the geology of the Pleistocene, the writer believes that about the beginning of the period there were extensive elevations of

large parts of the continent, perhaps of the whole of it. These elevations affected certainly the coastal regions and the regions of the Great Lakes. An important effect of these uplifts was the production of deep and wide excavations of the valleys of many of our large rivers. I accept the conclusions of our geologists that during the time of the last glaciation, the Wisconsin, the areas occupied by the ice were depressed, not greatly at and somewhat beyond the border, but increasingly so farther northward. The subsidence is attested by beds of marine shells along the coast at heights varying from 33 feet at Nantucket Island to 200 feet or more on the coast of Maine; on the coast of Labrador, 500 feet. Shell beds are found along the St. Lawrence River at heights of 250 feet; along Ottawa River, 450 feet. As to the Atlantic and Gulf coasts, from New Jersey to Mexico, it is a widely accepted theory that they have been sunken beneath the sea, once during the late Pliocene, three times during the Pleistocene, resulting in the production of 4 or more sets of marine terraces. The utter lack of marine fossils in these terraces, except for a few feet in the lowest one, seems sufficient to show the untenability of this theory. Other causes must be sought to explain the terraces. This is the work of the geologists; but they must not overlook the paleontology of these terraces.

Furthermore, it has been the custom to distribute the last three terraces with impartiality to widely separated times of the Pleistocene. The lowest one, having an elevation of perhaps from 40 to 100 feet above the sea, has been regarded as belonging to the late Pleistocene, about the time of the Wisconsin glacial stage. On the contrary, deposits on this lowest terrace, from New Jersey to the west coast of Florida, especially from North Carolina, contain an abundance of vertebrate fossils of the first interglacial stage, the Aftonian. That is, they contain the Aftonian elephant, *E. imperator*, species of mastodon found in only early Pleistocene deposits, many species of horses, camels, saber-tooth tigers, and various great edentates not found in later Pleistocene deposits. The low plain along the Gulf coast of Texas belongs to about the first interglacial, inasmuch as, down to sea-level, it contains remains of giant sloths, early Pleistocene elephants and mastodons, and camels. All those terraces then, low and high, must have been formed during the late Pliocene and the Nebraskan times. Since that time, no part of our coast south of New Jersey has been submerged by the sea, beyond a very few feet.

In Florida and farther north, beneath the deposits regarded by the

writer as belonging to the Aftonian interglacial stage, is a widely extended and deep accumulation of Pleistocene marine mollusks. I believe that this shell bed belongs to the Nebraskan stage. In Publication 322 of the Carnegie Institution of Washington, on pages 9–10, I provisionally referred to the Nebraskan, the Bone Valley phosphates and the Alachua clays. As to the Bone Valley deposits, it appears that an error was committed. Regarding the Alachua clays, it is possible that further exploration will show that distinct Pliocene and Miocene deposits are also present; but, so far as the writer knows, this has not been done.

The terraces of all the great rivers of Texas, the lower, as well as the upper ones, contain the vertebrate fossils which characterize the first interglacial stage. There is hardly any other explanation than that those great valleys were excavated during the late Pliocene and the early Pleistocene. Possibly they were excavated during the Nebraskan, refilled during the Aftonian, the fossils being then included, and the deposits removed partially at a later time.

5. THE AGE OF THE LAKE BONNEVILLE DEPOSITS

In his work on Lake Bonneville, G. K. Gilbert recognized two stages of high water. During the first high stage the yellow clays of the Lower Bonneville were laid down; during the second, the Upper Bonneville White Marls. Gilbert referred these marls to the last of his two recognized glacial stages, and this must be regarded as the Wisconsin. In these beds no vertebrates which might decide the geological age of the deposits were found; but Gilbert referred the remains found in Lake Lahontan to deposits believed to correspond in age to the Upper Bonneville. These remains belonged to a proboscidean, a bison, a horse, and a camel. At Astor Pass, in deposits regarded as equivalent to the Upper Bonneville, two species of horses, a camel, and a large tiger-like cat have been discovered, all identical with or closely related to, animals found at La Brea, California, of early Pleistocene age. These discoveries seem to push back the Upper Bonneville beds to about the time of the Aftonian, or early Kansan stage, unless Gilbert erred when he correlated the Bonneville beds with the Lahontan.

During the past summer, collections were made by Messrs. W. F. Foshag and S. H. Catheart, of H. G. Ferguson's party, on the Walker Lake beach and along Walker River. In these, remains of bison, a

large and a small horse, and a large species of camel were found. The camel is closely related to a large species found in Colorado, Idaho, Oregon, and perhaps Washington.

6. THE PLEISTOCENE OF THE PACIFIC COAST

The Pleistocene geology and vertebrate paleontology of the Pacific coast are of the highest interest. The early Pleistocene is well represented there; but many contrasts present themselves when the deposits are compared with those of the Atlantic coast. At no place along the coast of California did glaciers enter the sea. The coast was not at rest for long, but with oscillations, it was raised and depressed and raised again. When near sea-level the rocks were carved into terraces and these are now found at various heights up to 1,000 feet or more. Their origin is not doubtful, for marine fossils abound in them. At San Pedro, as we learn from Arnold's monograph[1] there are Upper Pliocene deposits filled with marine shells. These deposits are overlain by the Lower San Pedro Pleistocene from which about 250 species of marine organisms, mostly mollusks, have been collected. These indicate a cold climate. T. S. Oldroyd has recently studied[2] the Lower San Pedro mollusks, and he confirms Arnold's view regarding the climate. Above this deposit comes the Upper San Pedro, from which 250 species of marine mollusks have been secured. These fossils indicate a warmer climate than that of today. Arnold stated that the fauna resembled more nearly that now living two or three hundred miles further south. He believed also that this formation does not mark the close of the Pleistocene. He says: "All of this evidence, then, leads to the conclusion that there has been a sufficient lapse of time since the deposition of the Upper San Pedro strata to admit of marked faunal and orographic changes."

Now at San Pedro, in the Upper San Pedro beds, have been found remains of a bison, a horse, a *Nothrotherium*, a camel, and *Elephas imperator*, the last three animals being characteristic of early Pleistocene times. The evidence shows, therefore, that the Lower San Pedro belongs to the first, or Nebraskan, glacial stage and the Upper San Pedro to the Aftonian interglacial.

These same Upper San Pedro beds are found at many points along the coast of California. At Port Los Angeles, about 25 miles from San

[1] ARNOLD, R.: *The paleontology and stratigraphy of the marine Pliocene and Pleistocene of San Pedro, California*, Calif. Acad. Sci. Mem. 3. 1903.

[2] OLDROYD, T. S.: Proc. U. S. Nat. Mus. 65: art. 22. 1925.

Pedro, and about as many miles nearly directly west of Los Angeles, Arnold obtained 16 species of marine mollusks which he referred to the Lower San Pedro. The overlying beds did not bear fossils, but Arnold regarded them as probably Upper San Pedro. Farther east, 7 miles west of Los Angeles, is the La Brea locality, famous for its vertebrate fossils preserved in the asphalt pits. Here the Pleistocene, as described by Arnold,[3] is from 50 to 100 feet thick and consists of clay, sand, and gravel which have been brought down from the mountains. This material is impregnated with oil and asphalt. In the La Brea locality one must rely, not on marine fossils, but on land animals. The specimens collected by Merriam and his associates, and amounting to thousands, are usually in a fine state of preservation. The list of species, birds and mammals, is a large one. In general it may be said that the genera and the species of mammals are those which characterize the first interglacial stage elsewhere; and they may be referred without hesitation to the Aftonian.

7. THE PLEISTOCENE OF THE DESERT REGIONS OF OREGON AND WASHINGTON

At Christmas Lake, Oregon, 20 or more species of fossil mammals, more than 50 species of birds, and a few fishes have been collected. The mammals include four species of camels, the imperial elephant, and a horse; all of which the writer regards as indicative of the first interglacial stage.

At what is now a small settlement called Delight, about 12 miles northwest from Washtucna Lake, have been collected mammals including probably 2 species of horses, 3 camels, and a large ground-sloth (Mylodon). The writer regards the collection as belonging to the Aftonian interglacial stage.

8. THE LATER PLEISTOCENE AND ITS VERTEBRATE FOSSILS

In deposits laid down on the Wisconsin drift, especially in lakes, ponds, and swamps, are found 1 species of ground-sloth, 2 or more species of peccaries, 3 or 4 species of elephants, perhaps 2 mastodons, a moose, and a giant beaver, all now extinct. There have been discovered, so far as I can learn, no saber-tooth tigers, no horses, no tapirs, no camels, none of the many sloth-like animals that once existed, except the megalonyx. These deposits, which overlie the

[3] ARNOLD, R. and ELDRIDGE, G. H.: *The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, California.* U. S. Geol. Surv. Bull. 309: 186–195. 1907.

last drift sheet, and the fossil vertebrates found in them belong to the close of the Later Pleistocene.

Of the genera missing from the late Wisconsin fauna, the ground-sloths, the horses, the tapirs, various bisons, and saber-tooth tigers, some had survived the Kansan glacial stage. The species of the genera thus surviving are usually relatively few and the stages during which they became extinct, usually uncertain. *Mylodon*, *Bison antiquus*, and *B. latifrons*, and the tapirs dropped out probably during the Sangamon or soon after; the few horses apparently perished before or during the Wisconsin glacial stage. It seems, therefore, inexpedient to divide the post-Kansan vertebrates into two or more faunas.

PALEONTOLOGY.—*The genera* Pseudotextularia *and* Guembelina.

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The genera *Pseudotextularia* and *Guembelina* described from Europe also occur in the Upper Cretaceous of Mexico, and as the two are confused in Egger's work on the Foraminifera of the Cretaceous published in 1899[1] a few notes may help other workers on the foraminifera.

Pseudotextularia Rzehak, 1886

This genus was erected by Rzehak in 1886.[2] Later, in 1895,[3] Rzehak figured and described *Pseudotextularia varians*. This species seems to be identical with that later published by Egger as *Guembelina fruticosa*,[4] and it occurs in the Mendez member of the Upper Cretaceous of Mexico. As will be noted, other species connect the two faunas of Central Europe and Mexico. As shown by Rzehak in 1895 (pl. 7, figures 2 and 3) the early stages of *Pseudotextularia* are truly textularian, an alternating series of chambers on either side of an elongate axis, the apertures on the inner margin of newly added chambers. In the adult there occur isolated chambers near the periphery, subglobular in form, finally resulting in a spiral series about the margin, leaving a depressed area in the center. Well preserved Mexican specimens show this same series of characters. There are specimens, however, which do not attain this full generic character, and as figured by Rzehak (1895, plate 7, figure 1) still hold the textularian form. The ornamentation and general appearance are very similar in the two forms, however.

[1] EGGER. *Foraminiferen aus den Kreidemergeln der Oberbayerischen Alpen*. Abh. kon. bay. Akad Wiss. München, Cl. II, vol. 21, 1899.

[2] RZEHAK. Verh. Nat. Ver. Brünn, Sitz, 24: 8. 1886.

[3] RZEHAK. Ann. k. k. Nathist. Hofmuseums 10²: 217, *pl. 7, figs. 1–3*. 1895.

[4] EGGER, loc. cit., *pl. 14, figs. 8, 9*.